ATOMIC NITROGEN AS A CONSTITUENT FOR REGION F_1*

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ABSTRACT - The case of atomic nitrogen as one of the possible constituents for Region F_1 is studied by examining simultaneously the problem of dissociation of molecular nitrogen and that of the ionization of the resulting nitrogen atoms. The dynamic condition of the atmosphere is taken into account. It is shown that the maximum of ionization produced as a result of photoionization of atomic nitrogen lies between 150 to 200 km, for overhead sun, the best value being somewhere around 170 km. Further to give adequate ionization for the F_1-layer, the concentration of atomic nitrogen at the height where diffusive separtion takes place need not be larger than $\frac{1}{10}n(N_2)$.

Possible contribution from the ionization of atomic oxygen at third ionization potential is also discussed.

1. INTRODUCTION

An attempt has been made in the present paper to examine in some detail the case of atomic nitrogen as an active constituent for Region F_1. This has been considered necessary because of the fact that, although some half a dozen theories have been advanced so far, none has been found entirely satisfactory. The atmospheric constituents present in sufficient number at the level of the F_1-region are atomic oxygen, molecular nitrogen and possibly atomic nitrogen. Of these, the evidence of twi ight spectra precludes the possibility of N_2^+ (Bates, 1949), while atomic oxygen (at the first ionization potential) gives an ionization maximum at the wrong location somewhere between the E and F_1-regions (Bates and Seaton, 1950).

In the past, there has been a tendency to overlook possible ionization through atomic nitrogen. This was no doubt due to the general belief that the dissociation efficiency of N_2 is very low outside the auroral zone. This belief was fostered partly by the absence of a simple photodissociation process for N_2 analogous to that of O_2, and partly by the presence of molecular nitrogen spectra at the very high levels seen in sunlit aurora. The latter, particularly, made it difficult to believe that atomic nitrogen can be a constituent of the upper atmosphere at normal times to any degree of importance.

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Such objections have, however, been removed in recent years by the discovery of atomic nitrogen lines in airglow, (Courtes, 1950 ; Dufay, 1951) by the realization that atomic nitrogen may be produced appreciably by the dissociation recombination process (Bates, 1951 ; S. K. Mittra, 1951)

$$N_2 + h\nu \xrightarrow{\lambda < 795A} N_2 + (X') + e$$

$$N_2 + (X') + e \longrightarrow N(^2P) + N(^2D)$$

and, at low heights, by the Herzberg-Herzberg process (1948) :

$$N_2 + h\nu \xrightarrow{1150-1250A} N_2(a^1\Pi_g) \longrightarrow N + N,$$

and the suggestion that N_2^+ may also be formed by $N + N^+ \longrightarrow N_2^+$ (Nicolet, Pastiels, 1952 ; Nicolet 1950).

The case of atomic nitrogen as a possible source of the F_1-region has not been completely ignored in the past. Bates and Seaton (1950) have considered the possibility, but they arrived at the discouraging conclusion that, in order to produce the F_1-region, the concentration of atomic nitrogen at the level of the maximum should be as large as $3 \times 10^{10}/cm^3$*—a value difficult to accept. Whether the same result is obtained with recently deduced upper atmospheric characteristics (which are appreciably different from Bates and Seaton's) remains to be seen. Further, the problem of the distribution of atomic nitrogen at F_1-region heights has to be investigated. This involves a critical examination of the dissociation of N_2 at F_1-region heights, of the various processes of recombination of atomic nitrogen and consideration of a dynamical atmosphere.

The present paper attempts a simultaneous examination of the problem of N_2-dissociation and the problem of ionization of the resulting nitrogen atoms. The two problems are examined together with a view to obtaining a consistent overall picture. It is shown that atomic nitrogen appears to contribute at least partly to the ionization of Region F_1.

2. GENERAL CONSIDERATIONS

According to the theory of Chapman, the rate of electron production, q, due to the ionization of an atmospheric constituent by solar ultraviolet radiation is given by

$$q = AnQ_a \exp(-AnH \sec\chi) \qquad \ldots \quad (1)$$

where

A is the absorption coefficient for the constituent concerned.

n is the density of the constituent at any height h.

* In obtaining this value no account was taken of the attenuation of the incoming radiation through absorption by O and N_2 which is larger than that by N. Consideration of such absorption improves the situation appreciably.

Q_α is the number of solar photons at the relevant wave length reaching the terrestrial atmosphere.

χ is the solar zenith angle.

H is the scale height.

For an isothermal atmosphere, where the density is given by

$$n = n_0 e^{-z}$$

where z is the "reduced" height, Eq (1) gives, for the density at the height of the maximum ionization, :

$$n_m = \frac{\cos\chi}{AH} \tag{2}$$

For a non-isothermal atmosphere where the scale height H varies linearly with height :

$$H = H_0 + \beta z,$$

Eq (3) becomes

$$n_m = \frac{\cos\chi(1+\beta)}{AH} \tag{4}$$

Eq (4) gives the expression almost invariably used in discussing an ionization mechanism.

It is possible, however, to improve Eq (4).

The radiation responsible for the photoionization of the active constituent, i, is not absorbed by i alone, but frequently by other atmospheric constituents as well. Although such absorption is usually ignored, it it not always proper to do so, especially when, as in the case of atomic nitrogen, the active constituent is not the main absorbing constituent. This means that one has to replace Eq (1) by

$$q = A_i n_i Q_\alpha \exp\left[-(A_i n_i H_i + \textstyle\sum_k A_k n_k H_k)\sec\chi\right] \quad \cdots \quad (5)$$

where the subscript k refers to any atmospheric constituent, other than the one ionized, which absorbs the relevant radiation.

In the expressions (3) and (4) the recombination coefficient α is assumed constant. In Region F_1, α is very nearly so, but there are indications that α in this region probably depends on temperature and may be approximately represented by (A. P. Mitra, 1952)

$$\frac{H}{H_0} \tag{6}$$

where r is of order of unity.

In a study of Region F_1 we are concerned with the atmosphere at levels 150 km to 250 km, most of which is in diffusive equilibrium although the lower levels around 150 km are probably in a transitional state between mixing and diffusion. This means that, for most of the height levels of interest for the present work, H_k is different for the different constituents. The new expression replacing (4) now becomes :

$$A_i n_{im} + \sum_k A_k n_{km} = \frac{\cos\chi(1+\beta_i - r\beta_i)}{H_{im}} \quad \ldots (7)$$

The above expression is to be used in discussing the adequacy of any constituent whose distribution is determined only by the atmospheric temperature distribution.

Complications, however, appear when the distribution of the active constituent is determined by photochemical reactions rather than by the atmospheric temperature distribution. In the case of atomic nitrogen such complications exist. Consider that the distribution of atomic nitrogen in the upper atmosphere is given by

$$n(\mathrm{N}) = n_0(\mathrm{N})\xi'(h) \quad \ldots (8)$$

The absorption of the incoming radiation is mainly controlled by atomic oxygen and molecular nitrogen and, hence, to a first approximation, we may neglect the term $A_i n_i H_i \sec\chi$ in the exponent of Eq(5). We may, then, write :

$$N_e^2 = \frac{A(N) n_0(N) Q_h}{} \xi(h) \frac{H}{H_0} \exp\left[-\Sigma A_k n_{k0} H_{k0} \sec\chi \left(\frac{H}{H_c}\right)^{-1} \beta_k\right] \quad (9)$$

This gives, at the height of the maximum ionization,

$$\sum_i A_k n_k \sec\chi + \frac{r\beta_i}{H_i} + \frac{\xi'}{\xi} = 0 \quad \ldots (10)$$

where ξ' is the first derivative of ξ with respect to height.

Equation (10) is general and applies to any kind of distribution.

3. UPPER ATMOSPHERE CHARACTRISTICS

The region of interest in the present study is the height range 150 – 250 km. Rocket results regarding pressure are available up to 220 km ; but estimation of temperature and density from these results are made difficult by lack of proper information regarding the amount of dissociation of the constituents N_2 and O_2. There are several accounts of the probable distributions of the main constituents in this region based on rocket results (Gerson, 1952 ; Nicolet and Mange, 1954 ; Kallman, 1953 ; The Rocket Panel, 1952). These results differ somewhat because of the different temperature distributions and different dissociation rates assumed.

In calculating the concentrations, it is perhaps best to start with the temperature distribution as known. Of the various published distributions, the one given by Nicolet and Mange seems to us the most reasonable, but temperatures higher by as much as 25 percent are also possible.

In the present work three different models of temperature have been used (figure 1). Model 1 is the Nicolet-Mange model ; Model 2 is a possible upper limit of the temperatures and Model 3 is a likely compromise

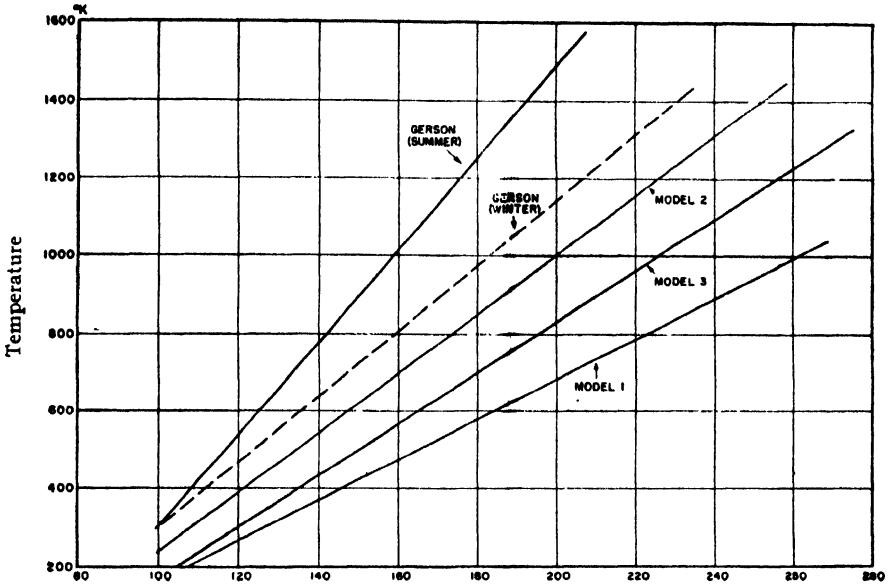

Fig. 1. Variation of atmospheric temperature with height for different models

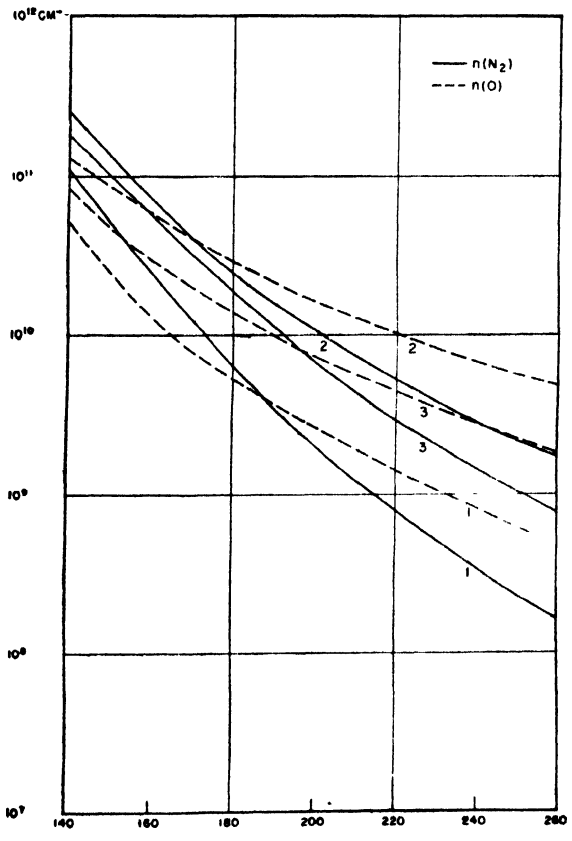

Fig. 2 Distribution of N_2 and O with height for different temperature models

between Models 1 and 2. The models used by Gerson are also shown ; but they are considered too high, in that they are based on the preliminary rocket data, and have not been used. The particle concentrations for N_2 and O for these different models are shown in figure 2. In each case the atmosphere is supposed to fall into diffusive separation above 160 km.

4. PHYSICAL DATA

4.1 *Absorption Coefficients*

We are interested in the absorption coefficients of the various constituents in three distinct wave length regions: one at $\lambda \leq 795$ A where photoionization of N_2 occurs, and another at $\lambda \leq 855$ A where ionization of N occurs, and the third at $\lambda \leq 910$ where the first ionization of atomic oxygen takes place. Values of the absorption coefficients for the different atmospheric constituents (Bates and Seaton, 1950; Clark, 1950 ; Chapman and Price, 1936 ; Weissler and Lee, 1952 ; Weissler, Lee and Mohr, 1952) for these wave lengths are given in Table I.

TABLE I

Absorption coefficient A in cm^2

$\lambda 795$				$\lambda 855$				$\lambda 910$		
N_2	O_2	O	N	N_2	O_2	O	N	N_2	O_2	O
10^{-17}	18×10^{-17}	5×10^{-18}	10^{-17}	3×10^{-18}	1.4×10^{-17}	3×10^{-18}	9×10^{-18}	1×10^{-18}	1×10^{-17}	2.5×10^{-18}

4.2 *Intensity of Solar Radiation*

The rocket results of Tousey et al (1951) between the wave lengths 1050A and 795A showed that the solar intensity between these wave lengths correspond to a flux density of 5×10^{11} to $3\times10^{12}/cm^2/sec$. On the assumption that the equivalent solar temperature is constant in this range, the corresponding temperature is $7200°K$. Also, with $Q_a = 10^{12}/cm^2/sec$ at $\lambda 1050$,

$$Q_a(\leq 855) = 2\times10^{10}\ cm^{-2}\ sec^{-1}$$
$$Q_a(\leq 790) = 3.6\times10^{9}\ cm^{-2}\ sec^{-1}$$
$$Q_a(\leq 910) = 8\times10^{10}\ cm^{-2}\ sec^{-1}$$

5. THE CASE OF ATOMIC NITROGEN

5.1 *Distribution of Atomic Nitrogen*

Atomic nitrogen is formed, mainly, by the dissociative recombination process (Bates, 1950 ; S. K. Mitra, 1951 ; Herzberg and Herzberg, 1948) :

$$N_2 + h\nu \xrightarrow{795\,A} N_2^+(X') + e$$
$$N_2^+(X') + e \longrightarrow N(^2P) + N(^2D) \qquad \ldots (11)$$

and by the Herzberg-Herzberg process :

$$N_2 + h\nu \xrightarrow{1150\text{Å}-1250\text{Å}} N_2(a^1\Pi_g) \longrightarrow N + N \qquad (12)$$

However, as Deb (1952) has shown, at heights of 150 km or above, the levels of interest in the present study, we need only consider the former process.

Nitrogen atoms so formed may disappear through a number of processes, such as :

$$N + N \xrightarrow{K} N_2 + h\nu \qquad \ldots (13)$$

$$N + O + M \longrightarrow NO + M \qquad (14)$$

$$N + N + M \longrightarrow N_2 + M \qquad (15)$$

$$N + NO \xrightarrow{k_3} N_2 + O \qquad \ldots (16)$$

Deb (1952) has discussed the relative importances of the reactions (13), (14) and (15) for the atmospheric model given by Gerson and has shown that processes (14) and (15) are much slower than process (13). With the atmospheric models 1, 2 and 3 used in the present work, it can be easily shown that the three-body recombination process given by (15) is never very important, while process (14) may be important if $\frac{n(O)}{n(N)}$ is 10^3 or more. At 200 km and above, the ratio is certainly not large enough to make process (14) important. Presumably, the process may be ignored for the lower levels of the F_1-region too, since, as will be pointed out later, $\frac{n(O)}{n(N)}$ is not expected to be much larger than 100 above 150 km.

Now consider the two-body process given by Eq (16). The rate is given by $k_3 n(N) n(NO)$. Hence

$$\frac{\text{Rate of process (16)}}{\text{Rate of process (13)}} = \frac{k_3}{K}\,\frac{n(NO)}{n(N)} \qquad (17)$$

The coefficient k_3 is temperature-dependent with values about 8×10^{-15} cm^3/s and 5×10^{-14} cm^3/s at 150 and 200 km where the temperatures are of the order of 450°K and 700°K. Hence, the ratio (17) is about 2×10^4 $[n(NO)/n(N)]$ at 150 km and about $[10^5 n(NO)/n(N)]$ at 200 km. Now, for a fixed atmosphere, NO has a concentration of about 10^8/cm^3 at 80 km (Nicolet, 1953 ; A. P. Mitra, 1953), so that $\frac{n(NO)}{n(N_2)} \simeq 2 \times 10^{-}$ This ratio will remain constant upto 150 km because of mixing and will be approximately the same even above 150 km, under conditions of diffusive separation, because the respective scale heights of NO and N_2 are not

appreciably different. A consequence of this is that the NO-concentration is about 2×10^4/cm^3 at 150 km and 10^3/cm^3 at 200 km. Now as will be shown later, $n(N) \simeq \frac{1}{100} n(N_2)$ at 150 km and perhaps about $\frac{1}{10} n(N_2)$ at 200 km. Hence, the ratio (17) becomes 0.3 at 150 km and about 0.2 at 200 km. One may, therefore, also ignore this process.

The height variation of the dissociation rate is of particular interest. Table II shows the variation of J, the rate coefficient of reaction (11) with height (for $X = 0°$) for the three models chosen :

TABLE II

J (per sec.)

Height (km)	Model		
	1	2	3
160	5.2×10^{-9}	1.3×10^{-13}	1.1×10^{-10}
180	1.5×10^{-8}	3.2×10^{-11}	1.3×10^{-9}
200	2.3×10^{-8}	3.3×10^{-10}	6.1×10^{-9}
220	2.9×10^{-8}	1.1×10^{-9}	1.1×10^{-8}
240	3.2×10^{-8}	2.9×10^{-9}	1.6×10^{-8}
260	3.1×10	5.4×10^{-9}	2.2×10^{-8}

The coefficient J, therefore, varies from a value of about 2×10^{-8} to the very small value of 10^{-13} in the height range of interest (160 – 260 km) and depending on the type of the atmosphere model used. These values lead us to the following conclusions :

(*i*) If equilibrium is allowed, then the concentration of atomic nitrogen around 200 km would be about 10^9/cm^3, and the total number of nitrogen atoms in a column of unit cross-section would be about 4×10^{16}/cm^2, 2×10^{16}/cm^2 and 3×10^{16}/cm^2 for models 1, 2 and 3, respectively. The corresponding values for molecular nitrogen are about 2×10^{17}/cm^2, 4×10^{17}/cm^2 and 3×10^{17}/cm^2.

(*ii*) Since the time, T_{eq}, required for $n_t(N)$ to grow to a value $e-1$ times the equilibrium value is given by

$$T_{eq} = \frac{1}{2\sqrt{[JKn(N_2)]}},$$

a period of several years is necessary in order that photochemical equilibrium may be established.

Now the time of mixing at these heights is probably of the order of a week, while the time of diffusion is of the order of several hours at 160 km and several minutes at 250 km (Nicolet and Mange, 1954). Somewhere between 150 and 200 km, therefore, the diffusive separation will begin to be effective. It is difficult to locate at present the height where it begins, but there seems to be no doubt that the process will be effective at least above 200 km. Thus, above 200 km, one may safely write :

$$n(\mathrm{N}) = n_{200}(\mathrm{N})\left(\frac{H}{H_0}\right)\left[1+\frac{1}{(\beta N)}\right]$$

where $\beta(\mathrm{N})$ is the scale height gradient relevant to atomic nitrogen.

Below 150 km, where the mixing effect still predominates, the concentration of atomic nitrogen will follow the main atmosphere. It is difficult to give an exact figure of the ratio $[n(\mathrm{N})/n(\mathrm{N}_2)]$ for these levels, but from examination of Table II and of the possible values of K, Nicolet's (1952) value of 1/100 seems reasonable.

The region between 150 to 200 km is probably a transition region. It is possible that diffusive separation begins to predominate even at 160 km in which case the transition region may be confined between 150 to 160 km.

For purposes of calculation, two different non-equilibrium distributions have been used. In the first (case I) mixing predominates up to about 150 km with the ratio $n(\mathrm{N})/n(\mathrm{N}_2) = 1/100$; transition from mixing to diffusive separation occurs between 150 to 200 km, the ratio $n(\mathrm{N})/n(\mathrm{N}_2)$ increasing to a value of 1/10 at 200 km ; above 200 km atomic nitrogen is distributed according to its own scale height. In the second case (case II) transition is supposed to occur between a narrow strip at 140-150 km with the concentration falling according to its own scale height above 150 km. The real situation is probably somewhere between these two.

The value $\frac{n(\mathrm{N})}{n(\mathrm{N}_2)} = \frac{1}{10}$ is a conservative value, and has been chosen on the basis of the values mentioned before, of the total number of nitrogen atoms * and molecules in a column of unit cross-section. These values are such that they allow for an average ratio of about 1/10 over the entire region even when mixing transfers the nitrogen atoms from one place to another.

5.2. *Atomic Nitrogen as a Constituent for Region F_1*

The experimental results regarding F_1 are that the equivalent height of maximum ionization is about 190 km at summer noon and about 210 km at winter noon for a medium latitude The actual heights are not known, but they may be appreciably lower than the above values. The electron density at the height of the maximum ionization is about $2.5 \times 10^5/\mathrm{cm}^3$ for sunspot minimum, and $4 \times 10^5/\mathrm{cm}^3$ for sunspot maximum.

Consider now the photoionization of atomic nitrogen for the distributions

* Estimated under equilibrium conditions.

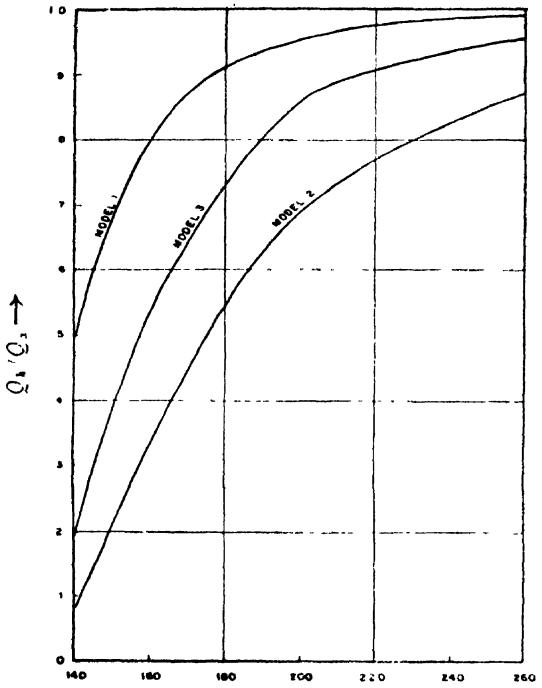

Fig. 3 Q_A/Q_a as a function of height

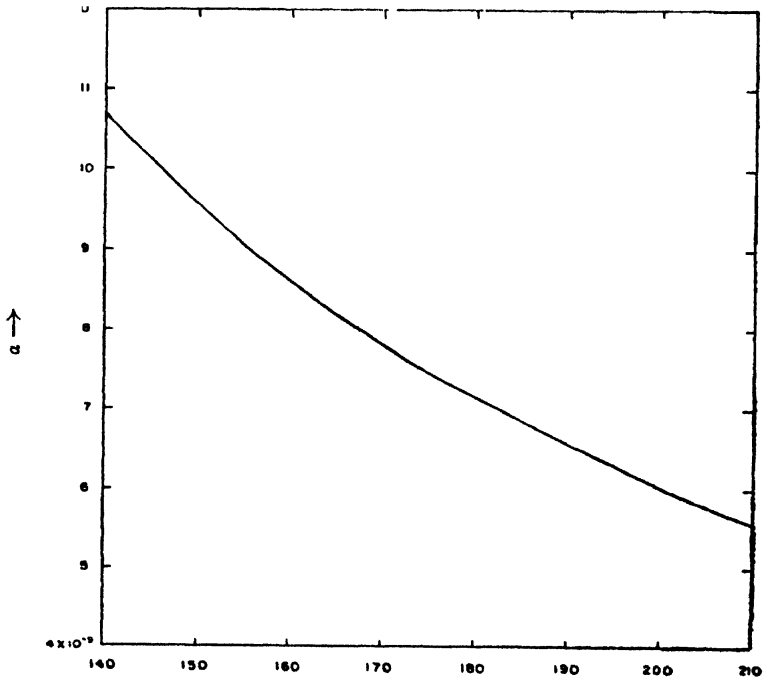

Fig. 4. Probable variation of recombination coefficient.

(cases I and II) indicated in the previous section for an atmosphere in which photochemical equilibrium cannot be reached. Now, absorption of the incoming solar radiation by atomic nitrogen is negligible compared to that by oxygen and molecular nitrogen for this case. Under these conditions the intensity of the ionizing radiation at any height will be independent of whichever distribution of atomic nitrogen we select. In figure 3 the intensity of this radiation at various heights is plotted as a ratio of the unattenuated intensity for the three atmospheric models. The height of maximum ionization and the maximum ionization densities calculated with the help of these figures (and for the recombination coefficient distribution given in figure 4) are shown in Table III. For comparison purposes, the results for the idealised case of photochemical equilibrium are also shown.

TABLE III

Height and concentration of maximum ionization for different cases

Model	Non-equilibrium				Equilibrium	
	Case I		Case II			
	h_{max} (km)	N_e (cm^{-3})	h_{max} (km)	N_e (cm^{-3})	h_{max} (km)	N_e (cm^{-3})
1	160	9×10^4	150	2.5×10^5	164	2.9×10^5
2	218	1.5×10^5	175	2.6×10^5	222	1.8×10^5
3	182	1.4×10^5	160	2.9×10^5	192	2.4×10^5

It may be remarked here that for such cases as in II (non-equilibrium case), the only assumption needed for determination of the location of maximum ionization is the assumption of diffusive separation. If it is accepted that such a separation takes place somewhere below the maximum of the F_1-layer, then one is permitted to use, for the regions of interest, the expression :

$$n(\mathrm{N}) = n_0(\mathrm{N})\left(\frac{H}{H_0}\right)^{-\left[1+\frac{1}{\beta(\mathrm{N})}\right]}$$

which yields, for h_m,

$$2Hn(\mathrm{N_2})\sum_k A_k n_{mk} \sec \chi = 1 + 2\beta(\mathrm{N_2}) - 2r\beta(\mathrm{N_2})$$

The results for such a case for overhead sun have already been given (case II, Table III). They are also indicated in figure 5 where the results for other values of χ have been included.

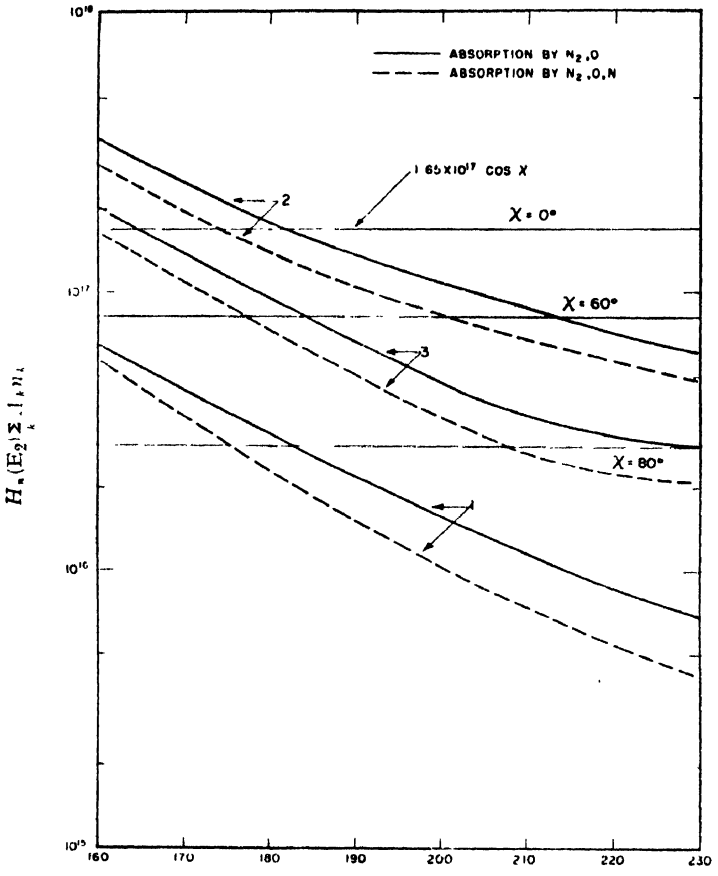

Fig. 5. Location of maximum ionization for the second non-equilibrium case

6. DISCUSSION

It seems probable that, for a dynamic atmosphere, the maximum of ionization produced as a result of the photoionization of atomic nitrogen lies between 150 to 200 km (for $\chi = 0°$) depending on the atmospheric model assumed; the best value being somewhere around 170 km. There is still a discrepancy of the order of a scale height between the theoretical value and the observed equivalent height. But, as Nicolet (1952) has pointed out, the measured equivalent heights may differ from the actual heights by such an amount.

In order that atomic nitrogen should give adequate ionization for the F_1-layer, the concentration of atomic nitrogen at the height where diffusive separation takes place need not be larger than $\frac{1}{10}\, n(N_2)$. Such a ratio is not impossible. It seems likely, therefore, that atomic nitrogen will contribute at least partly to the ionization of the F_1-region.

The case of atomic oxygen has not been discussed so far. Ionization of atomic oxygen at the first ionization potential is not suitable. With

$A(O)=2.5\times10^{-18}$ cm^2, $A(O_2)=1.1\times10^{-17}$ cm^2 and $A(N_2)=3\times10^{-18}$ cm^2 for $\lambda\leq 910$A, it is easily shown that the ionization maximum is around 140 km for $\chi=0°$) for all the the three models chosen. But although ionization of atomic oxygen at the first ionization potential does not seem adequate, ionization of O at the third ionization potential (18.5 eV) may be of importance. * $A(O)$ at this wave length is about 10^{-17} cm^2, of the same order as $A(N)$ at $\lambda855$, so that the ratio of ionization yield through atomic oxygen at $\lambda\leq 665$ and that through atomic nitrogen at $\lambda\leq 885$ is given by

$$\frac{q(O)}{q(N)}\simeq\frac{n(O)Q(O)}{n(N)Q(N)}$$

$Q(O)/Q(N)$ is probably of the order of 10^{-2} so that $n(O)/n(N)$ should be about 10^2 or larger in order that ionization through atomic oxygen should be important. At lower F_1 heights such a ratio presumably does exist, but at higher levels (i.e. at the level of the maximum ionization and above $n(O)/n(N)$ may not be large enough. Another interesting point about ionization of O at $\lambda\leq 655$ is that the ionization maximum occurs ta a height around 200 km i.e. at the correct height.

It has been pointed out that the F_1 and the F_2-regions may both arise from a *single* ionization mechanism by a process of bifurcation (Bradbury, 1938 ; Bates, 1949 ; Mitra, 1952 ; Ghosh, 1955 ; Chatterjee, 1953). On this hypothesis the theory of F_1 formation will have bearing on the F_2-region as well. Although the theoretical arguments for such a hypothesis seems well-grounded, to date no experimental confirmation has been available. Some confirmation was sought during the present work by studying the departures of the hourly values of the ordinary wave critical frequencies from the hourly means for both the F_1 and F_2-layers using the following parameters :

$$P(F_1)=\frac{(foF_1)^2-\overline{(foF_1)^2}}{\overline{(foF_1)^2}}\times 100\%$$

$$P(F_2)=\frac{(foF_2)^2-\overline{(foF_2)^2}}{\overline{(foF_2)^2}}\times 100\%$$

$P(F_1)$ and $P(F_2)$ have been plotted against each other as a scatter diagram. The correlation is high—a typical case is shown in figure 6.

Now, the ionization of F2 increases by a factor of 3 from sunspot minimum to sunspot maximum and that for F_1 by about 1.6. The resulting value $\frac{\Delta N(F_2)}{\Delta N(F_1)}\simeq 3.4$ may be considered as an amplification factor and must depend, primarily, on changes in solar intensity ; since local dynamical effects

* The author is grateful to Dr. Nicolet for pointing out this possibility and for interesting discussion on this point.

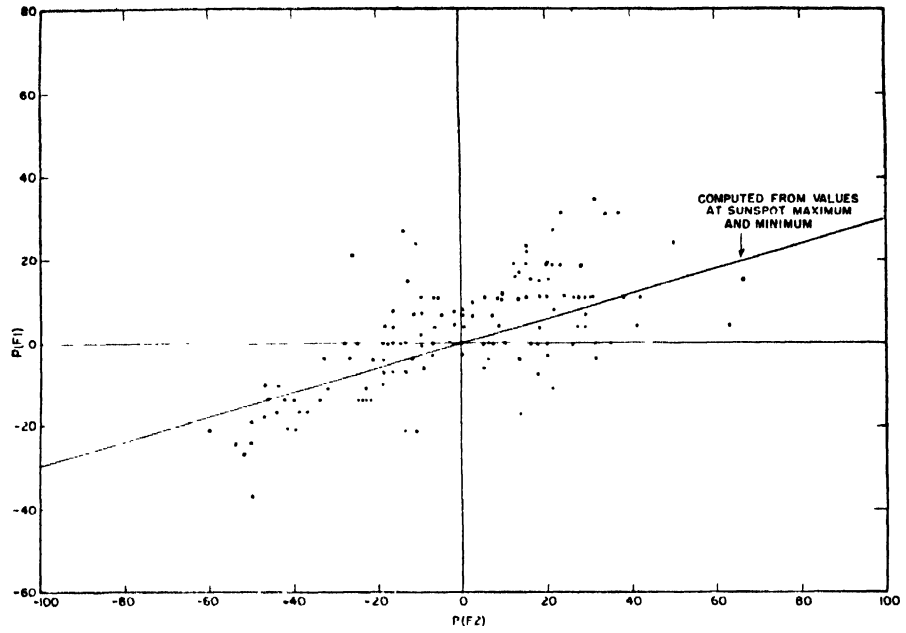

Fig 6. Correlation between the fluctuations of f_0F_1 and f_0F_2 for May 1948, Washington

will be averaged out. It is a remarkable fact that the points in figure 6 do scatter around the straight line giving $\frac{\Delta N(F_2)}{\Delta N(F_1)} \simeq 3.4$. If this is interpreted as indicating that fluctuations in F_1 and F_2-ionizations are due mostly to fluctuations in the relevant solar intensity, then it seems likely (though not certain) that the same radiation is involved in the ionizations of F_1 and F_2. If this is accepted, then the theory of bifurcation requires that : (1) the F_1-ionization should also supply the ionization of F_2 and that (2) the scale heights and recombination coefficient of the active constituent should be consistent with our ideas of these parameters not only at F_1-region but at F_2-region as well.

There is little doubt that at F_1 and F_2 heights, recombination occurs through a dissociation process of the type (Bates and Massey, 1947) : $XY^+ + e \longrightarrow X' + Y'$, where XY^+ may be formed through

$$Z^+ + XY \longrightarrow XY^+ + Z$$

For the charge transfer process to be possible, the ionization potential of XY must be less than that of Z. This means that the molecule XY cannot be N_2. The only atmospheric molecules which have sufficiently low ionization potentials are O_2 and NO of which the concentration of NO at F-region heights is negligible. If, therefore, we identify XY as O_2, then Z^+ would be either O^+ or N^+. Since the rates for these processes are not known, it is not possible to choose between them at present. However, this point has

to be remembered in evaluating the contributions of O^+ and N^+ to the F_1-layer.

The typical values of scale heights associated with F_1 and F_2-ionizations are about 30 km and 70 km respectively (S. K. Mitra, 1952). Although these values are by no means exact, particularly the values for F_2-region (Gerson, 1951), we may consider that they are of the right order. Now, with diffusion starting at 160 km, the values of scale heights associated with individual atmospheric constituents, are given in Table IV.

TABLE IV

200 km (F_1)				300km (F_2)			
$H(O)$	$H(N)$	$H(N_2)$	H'	$H(O)$	$H(N)$	$H(N_2)$	H'
39.0	44.6	22.3	30	69.0	78.8	39.4	70

H' = scale height obtained from ionospheric measurements

Even allowing for the uncertainties in the ionospheric measurements, $H(N_2)$ appears to be too low for both F_1 and F_2-regions and suggests, once again, that N_2 is probably not the active constituent. On the other hand, both $H(O)$ and $H(N)$ are of the right order.

It appears, therefore, that ionizations from both atomic nitrogen and oxygen ($\lambda \leq 655$) are likely to contribute to the F_1 and F_2-layers ; though nothing can be said at present about their respective proportions.

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